Downscaling Methods

Overview

We use a variation of the constructed analogs method described by (Pierce et al. 2014) to downscale CMIP5 projections for the Red River, Vietnam. Our modified method is termed **Constructed Analogs with Single Anomaly Analog** (**CASAA**). Key differences from (Pierce et al. 2014) include:

- We use anomalies for downscaling both temperature and precipitation. In contrast, (Pierce et al. 2014) use anomalies for downscaling temperature and absolute values for downscaling precipitation. We found that anomalies provided better performance when downscaling precipitation and helped to avoid instability issues with the scaling factor described in *section 3.b.4* and *Appendix d* of (Pierce et al. 2014). Because we use anomalies, our precipitation scaling factor is additive instead of multiplicative.
- For a specific chosen analog, we preserve the high-resolution wet-dry spatial pattern. Unlike (Pierce et al. 2014), we make sure the applied scaling factor (*section 3.b.4* and *Appendix d*) does not change any high-resolution grid cells from wet to dry in the high-resolution analog.
- We do not use the localized analog selection procedure of (Pierce et al. 2014). We select a best match analog for a specific day using the entire Red River spatial domain.

Details of the Red River CASAA method are provided below.

Symbols

$\boldsymbol{O}_{base\text{-}h}$	high-resolution gridded observations for historical base time period
$\boldsymbol{O}_{base\text{-}c}$	coarsened and smoothed high-resolution gridded observations for historical base time period
$\boldsymbol{M}_{base\text{-}c}$	smoothed modeled values for historical base time period
$\boldsymbol{M}_{fut\text{-}c}$	smoothed modeled values for time period to downscale
$\boldsymbol{M}_{fut\text{-}h}$	high-resolution downscaled modeled values for time period to downscale
$\overline{O}_{base\text{-}h}$	high-resolution gridded observation monthly normals for historical base time period
$\delta\boldsymbol{O}_{base\text{-}h}$	high-resolution gridded observation anomalies for historical base time period
$\delta\boldsymbol{O}_{base\text{-}c}$	coarsened and smoothed high-resolution gridded observation anomalies for historical base time period
$\overline{M}_{base\text{-}c}$	smoothed modeled monthly normals for historical base time period
$\overline{M}_{fut\text{-}c}$	smoothed modeled monthly normals for time period to downscale
$\overline{M}_{fut\text{-}h}$	high-resolution downscaled modeled monthly normals values for time period to downscale

$\boldsymbol{\delta M_{fut\text{-}c}}$ smoothed modeled anomalies for time period to downscale

Δ_c anomaly difference at smoothed coarse spatial scale

$\widehat{\delta O}_{base\text{-}h}$ high-resolution gridded observation anomalies for historical base time period modified by anomaly difference at smooth coarse spatial scale

$\boldsymbol{\delta}\overline{M}_c$ monthly normal difference for modeled values in two different time periods at smoothed coarse spatial scale

$\boldsymbol{P_{daily}}$ daily precipitation total

$\boldsymbol{P_{clim}}$ average normal daily precipitation total

$\boldsymbol{P_{anom}}$ daily precipitation total anomaly

$\boldsymbol{T_{daily}}$ daily average temperature

$\boldsymbol{T_{clim}}$ average normal daily temperature

$\boldsymbol{T_{anom}}$ daily temperature anomaly

Constructed Analogs Downscaling: Daily Precipitation

1. Set training historical base time period for which high-resolution gridded observations, $\boldsymbol{O_{base\text{-}h}}$, are available. Example: Aphrodite 1961-2007 period-of-record.
2. Create coarse version of observation gridded dataset that matches the model grid to be downscaled. Resample coarse version of observations back to high-resolution grid using bicubic smoothing to create $\boldsymbol{O_{base\text{-}c}}$.
3. Using bicubic smoothing, create smoothed version of coarse-scale modeled values, $\boldsymbol{M_{fut\text{-}c}}$, that matches high resolution grid.
4. Convert all gridded observations and modeled values to daily precipitation anomalies relative to a common base period ($\boldsymbol{\delta O_{base\text{-}h}}$, $\boldsymbol{\delta O_{base\text{-}c}}$, $\boldsymbol{\delta M_{fut\text{-}c}}$).
    a. Anomaly formula for single day: $\boldsymbol{P_{anom}} = \boldsymbol{P_{daily}} / \boldsymbol{P_{clim}}$ where $\boldsymbol{P_{daily}}$ is the total precipitation for the day, $\boldsymbol{P_{clim}}$ is the average daily precipitation for the day's month calculated over the common base time period, and $\boldsymbol{P_{anom}}$ is the daily anomaly.
5. Loop through modeled dates to be downscaled
    a. Downscale $\boldsymbol{\delta M_{fut\text{-}c}}$ for single day $\boldsymbol{i}$
        i. Generate pool of potential daily anomaly analogs from $\boldsymbol{\delta O_{base\text{-}c}}$. The pool includes all historical days within 45 days of the $\boldsymbol{i}$ day-of-year being downscaled (91 day moving window).
        ii. Calculate spatial root-mean-square error (RMSE) for each potential historical analog in $\boldsymbol{\delta O_{base\text{-}c}}$
        iii. Select single day, $\boldsymbol{a}$, with smallest RMSE as the historical analog, $\boldsymbol{\delta O_{base\text{-}c}(a)}$
        iv. Calculate additive anomaly differences, $\boldsymbol{\delta}\Delta_c$, between $\boldsymbol{\delta M_{fut\text{-}c}(i)}$ and $\boldsymbol{\delta O_{base\text{-}c}(a)}$: $\boldsymbol{\delta}\Delta_c = \boldsymbol{\delta M_{fut\text{-}c}(i)} - \boldsymbol{\delta O_{base\text{-}c}(a)}$
        v. Get high-resolution gridded observation anomalies, $\boldsymbol{\delta O_{base\text{-}h}(a)}$, corresponding to the historical date for $\boldsymbol{a}$.
        vi. Apply corresponding individual grid cell $\boldsymbol{\delta}\Delta_c$ values to all non-zero precipitation grid cells in $\boldsymbol{\delta O_{base\text{-}h}(a)}$ as: $\widehat{\delta O}_{base\text{-}h}\boldsymbol{(a)} = \boldsymbol{\delta O_{base\text{-}h}(a)} + \boldsymbol{\delta}\Delta_c$

vii. Set any $\widehat{\delta O}_{base\text{-}h}(\boldsymbol{a})$ values to their original value, $\boldsymbol{\delta O_{base\text{-}h}(a)}$, that are ≤ 0 after applying $\boldsymbol{\delta}\Delta_c$.

viii. Multiply $\widehat{\delta O}_{base\text{-}h}(\boldsymbol{a})$ by corresponding climatology $\overline{O}_{base\text{-}h}$ for month ***m*** to get final downscaled values for day ***i***: $\boldsymbol{M_{fut\text{-}h}} = \widehat{\delta O}_{base\text{-}h}(\boldsymbol{a}) \times \overline{O}_{base\text{-}h}(\mathbf{m})$

Constructed Analogs Downscaling: Daily Temperature

1. Set training historical base time period for which high-resolution gridded observations, $\boldsymbol{O_{base\text{-}h}}$, are available. Example: Aphrodite 1961-2007 period-of-record.
2. Create coarse version of observation gridded dataset that matches the model grid to be downscaled. Resample coarse version of observations back to high-resolution grid using bicubic smoothing to create $\boldsymbol{O_{base\text{-}c}}$.
3. Using bicubic smoothing, create smoothed version of coarse-scale modeled values, $\boldsymbol{M_{fut\text{-}c}}$, that matches high resolution grid.
4. Convert all gridded observations to daily temperature anomalies relative to a common base period ($\boldsymbol{\delta O_{base\text{-}h}}$, $\boldsymbol{\delta O_{base\text{-}c}}$).
    a. Anomaly formula for single day: $T_{anom} = T_{daily} - T_{clim}$ where T_{daily} is the average temperature for the day, T_{clim} is the average daily temperature for the day's month calculated over the common base time period, and T_{anom} is the daily anomaly.
5. Calculate monthly normals, $\overline{M}_{base\text{-}c}$, for $\boldsymbol{M_{base\text{-}c}}$
6. Set time periods to downscale individually (~30 year periods). Example: 1976-2005, 2006-2039, 2040-2069, 2070-2099.
7. Loop through time periods to downscale
    a. Downscale monthly normals for $\boldsymbol{M_{fut\text{-}c}}$ over the time period to downscale
        i. Calculate monthly normals, $\overline{M}_{fut\text{-}c}$, for $\boldsymbol{M_{fut\text{-}c}}$ over time period to downscale
        ii. Calculate monthly normals difference, $\boldsymbol{\delta}\overline{M}_c$, for each month between $\overline{M}_{fut\text{-}c}$ and $\overline{M}_{base\text{-}c}$ as $\boldsymbol{\delta}\overline{M}_c = \overline{M}_{fut\text{-}c} - \overline{M}_{base\text{-}c}$
        iii. Loop through each month, ***m***
            1. Treat $\boldsymbol{\delta}\overline{M}_c$ for ***m*** as a daily anomaly
            2. Generate pool of potential daily anomaly analogs from $\boldsymbol{\delta O_{base\text{-}c}}$. The pool includes all historical days within 45 days of month ***m***.
            3. Calculate spatial root-mean-square error (RMSE) for each potential historical analog in $\boldsymbol{\delta O_{base\text{-}c}}$
            4. Select 30 ***a*** days with smallest RMSE as the historical analogs, $\boldsymbol{\delta O_{base\text{-}c}(30a)}$.
            5. Loop through $\boldsymbol{\delta O_{base\text{-}c}(30a)}$
                a. Calculate additive differences, Δ_c, between $\boldsymbol{\delta}\overline{M}_c$ values and historical analog anomaly values: $\Delta_c = \boldsymbol{\delta}\overline{M}_c - \boldsymbol{\delta O_{base\text{-}c}(a)}$
                b. Get high-resolution gridded observation anomalies, $\boldsymbol{\delta O_{base\text{-}h}(a)}$, corresponding to the historical date for ***a***.

c. Apply Δ_c to $\boldsymbol{\delta O_{base\text{-}h}(a)}$ as: $\widehat{\delta O}_{base\text{-}h}(a) = \delta O_{base\text{-}h}(a) + \Delta_c$

d. Add $\widehat{\delta O}_{base\text{-}h}(a)$ to corresponding climatology $\overline{O}_{base\text{-}h}$ for month ***m*** to get downscaled normal values, $\overline{M}_{fut\text{-}h}$, for month ***m***.

6. Calculate average of the $\overline{M}_{fut\text{-}h}(30a)$ downscaled values. This is the final downscaled monthly normals, $\overline{M}_{fut\text{-}h}$, for month ***m***.

b. Convert modeled values for time period to downscale to daily temperature anomalies, $\boldsymbol{\delta M_{fut\text{-}c}}$, relative to $\overline{M}_{fut\text{-}c}$.

i. Loop through modeled time period dates to be downscaled

1. Downscale $\boldsymbol{\delta M_{fut\text{-}c}}$ for single day ***i***

a. Generate pool of potential daily anomaly analogs from $\boldsymbol{\delta O_{base\text{-}c}}$. The pool includes all historical days within 45 days of the ***i*** day-of-year being downscaled (91 day moving window).

b. Calculate spatial root-mean-square error (RMSE) for each potential historical analog in $\boldsymbol{\delta O_{base\text{-}c}}$

c. Select single day, ***a***, with smallest RMSE as the historical analog, $\boldsymbol{\delta O_{base\text{-}c}(a)}$

d. Calculate additive anomaly differences, Δ_c, between $\boldsymbol{\delta M_{fut\text{-}c}(i)}$ and $\boldsymbol{\delta O_{base\text{-}c}(a)}$: $\Delta_c = \delta M_{fut\text{-}c}(i) - \delta O_{base\text{-}c}(a)$

e. Get high-resolution gridded observation anomalies, $\boldsymbol{\delta O_{base\text{-}h}(a)}$, corresponding to the historical date for ***a***.

f. Apply corresponding individual grid cell Δ_c values to $\boldsymbol{\delta O_{base\text{-}h}(a)}$ as: $\widehat{\delta O}_{base\text{-}h}(a) = \delta O_{base\text{-}h}(a) + \Delta_c$

g. Add $\widehat{\delta O}_{base\text{-}h}(a)$ to corresponding downscaled climatology $\overline{M}_{fut\text{-}h}$ for month ***m*** to get final downscaled values for day ***i***: $M_{fut\text{-}h} = \widehat{\delta O}_{base\text{-}h}(a) + \overline{M}_{fut\text{-}h}(m)$.

References

Pierce, D. W., D. R. Cayan, and B. L. Thrasher, 2014: Statistical Downscaling Using Localized Constructed Analogs (LOCA)*. *J. Hydrometeorol.*, 15, 2558–2585.